FUEL CELL
APPLIED RESEARCH PROJECT

FINAL REPORT

Reporting Period: November 11, 2003 to March 31, 2005

Lee Richardson, Coordinator, Fuel Cell

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NORTHERN ALBERTA INSTITUTE OF TECHNOLOGY
11762 – 106 Street
Edmonton, Alberta
Canada T5G 2R1

Disclaimer

Abstract

Since November 12, 2003, Northern Alberta Institute of Technology has been operating a 200 kW phosphoric acid fuel cell to provide electrical and thermal energy to its campus. The project was made possible by funding from the U.S. Department of Energy as well as by a partnership with the provincial Alberta Energy Research Institute; a private-public partnership, Climate Change Central; the federal Ministry of Western Economic Development; and local natural gas supplier, ATCO Gas. Operation of the fuel cell has contributed to reducing NAIT's carbon dioxide emissions through its efficient use of natural gas.

List of Abbreviations and Acronyms

AERI	Alberta Energy Research Institute
AF	Available Factor
AH	System Available Hours
BTU	British Thermal Unit
CCC	Climate Change Central
CM	Cooling Module
CO_2	Carbon Dioxide
DOE	Department of Energy
ESD	Emergency Shutdown
FOH	Forced Outage Hours
FOR	Forced Outage Rate
Hr	Hour
HT	High temperature
GJ	Gigajoules
GTI	Gas Technology Institute
kg	Kilogram
kW	Kilowatt
kWe	Kilowatt electrical
kWt	Kilowatt thermal
LT	Low Temperature
MBTU	Thousand British Thermal Unit
MDSP	Master Microprocessor
MDT	Mean Down Time
MTBRFO	Mean Time Between Forced Outages
MW	Megawatt
MWhr	Megawatt per Hour
NAIT	Northern Alberta Institute of Technology
PAFC	Phosphoric Acid Fuel cell
PEM	Proton Exchange Membrane
PH	Period Hours
POD	Period of Demand
ppm	Parts per million
PSD	Planned Shut Down
RSH	Reserve Standby Hours
SF	Service Factor
SH	System Operating Service Hours
SOF	Schedule Outage Factor
SOH	Scheduled Outage Hours
SOFC	Solid Oxide Fuel Cell
UPS	Uninterrupted Power Supply
US	United States
UTC	United Technologies Company
V	Volt

VAC	Volt Alternating Current
VDC	Volt Direct Current
WED	Western Economic Diversification

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Graphical Materials

Introduction

The intent of NAIT Fuel Cell Project is to investigate and demonstrate ways of utilising the electrical and heat energy produced by fuel cells and to develop a fuel cell education program. The project will also provide an opportunity for the public to learn interactively about fuel cells and their future impact on society.

HISTORY OF PURCHASE

On April 1, 2003 the Northern Alberta Institute of Technology (NAIT), ATCO Gas, Western Economic Diversification (WED), Climate Change Central (CCC), and the Alberta Energy Research Institute (AERI) formed a project partnership. The project purpose was to purchase a 200 kW PAFC unit and a 5 kW SOFC unit. The 200 kW fuel cell was purchased from UTC Fuel Cells, a division of United Technologies Ltd. of South Windsor, CT. A 5 kW fuel cell has been purchased from Acumentrics of Westwood, MA. It is scheduled for delivery and commissioning in July 2005.

INTERPRETIVE CENTRE

An interpretive centre has been built around the 200 kW PAFC and was officially opened in October 2004. It showcases the first high-voltage, commercially operated fuel cell in Canada and is designed to provide the general public with an opportunity for interactive learning about fuel cell technology, environmental impacts, and the fuel cell project. It will also provide a venue for junior high and high school students to acquire direct knowledge of fuel cells in operation.

The interpretive centre is designed to provide information through static and interactive displays that will enable students to complete school projects related to environmental and energy issues.

Executive Summary

The NAIT Fuel Cell Applied Research Project has three main objectives. One is to provide training for NAIT students in fuel cell related courses including general knowledge, operation, and maintenance using the 5 kW fuel cell in the Power Engineering lab. The second objective is to provide information to the general public and school students through an interpretive centre built around the 200 kW fuel cell. The third objective is to involve NAIT in applied research into fuel cells and their application.

A 200 kW Phosphoric Acid Fuel Cell (PAFC), a PC25C, has been purchased from UTC Fuel Cells, a Division of United Technologies and has been producing power at or near full load since November 12, 2003. As of March 4, 2005, the fuel cell has supplied 2092 MWhr of electrical energy into the NAIT grid. It has also produced 2323 MWhr of thermal energy of which 1610 MWhr have been captured and used in the NAIT heating system to supply heat to the NAIT pool, domestic hot water system, and boiler feedwater heating.

Heat energy of the incoming fuel and electrical and thermal energy produced is continuously monitored and recorded. The gross efficiency of the unit is 73.3% (61.1% net efficiency) with possibilities of increase from greater use of the thermal energy produced. The rate of heat capture has been increasing as systems controls are adjusted and heat loads added.

A 5 kW Solid Oxide Fuel Cell (SOFC) has been purchased and will be installed in the Power Engineering lab and used as a tool to enhance student learning for Power Engineering students as well as other technologies such as Electrical Engineering and Mechanical Engineering. The SOFC will be used to test different fuels and compare efficiencies with gas fired boiler/generator units. Delivery of the 5 kW fuel cell is scheduled for October 2005. A proposal has been submitted to purchase smaller fuel cell equipment for a lab course.

The SOFC will also be used for applied research purposes. Discussions are currently underway with the federal National Research Council with the view of collaboration between NAIT and private firms to carry out applied research into aspects of fuel cell applications. As well the University of Alberta and University of Calgary have expressed interest in working with NAIT on the SOFC unit. Preliminary discussions have also been opened a Texas based research group that may involve cooperation on research into the application at NAIT.

A fuel cell course has been written that will be offered to Power Engineering day program students in the fall of 2005 and to the general public as an evening course. The day program course will include laboratory experiences with the 5 kW SOFC and several 1 kW PEM Nexa™ units. This equipment will afford the students an opportunity to study the effects of a variety of load and operating conditions on fuel cells.

An interpretive centre has been built around the 200 kW phosphoric acid fuel cell. The centre employs both static and interactive displays that describe operation of the various components of the fuel cell and discuss environmental issues and solutions. It is open to NAIT students, the public, and High School and Junior High School students. It will be used to enhance student and public awareness of alternative energy systems and the environment. Numerous tours of the facility have been conducted.

Experimental

The focus of the NAIT Fuel Cell Applied Research Program is fourfold.

- It proposes to use the PC25C fuel cell to demonstrate the capability of fuel cells to provide combined heat and power energy to the facility in a manner that is efficient and results in a reduction in greenhouse gases produced by the facility.

- Since NAIT is an educational institution, the intent is to use the PC25C fuel cell as part of a teaching and learning environment for our students in the Power Engineering and other departments. The fuel cell, along with a 5 kW SOFC machine and smaller units, will form the basis of a fuel cell basics course that will introduce students to fuel cells and their operating characteristics.

  As well, the PC25C will also be part of an evening continuing education course that will be available to the public.

- NAIT has built an interpretive centre around the PC25C fuel cell in an effort to engage public interest in alternate energy production methods and encourage awareness of environmental issues.

- The program also intends to utilize the 5 kW SOFC to engage in research into fuel cell applications and performance.

DATA COLLECTION SYSTEM

An important part of the fuel cell program is the collection of data in order to track the energy usage efficiency. This requires measurement and recording of energy inputs and outputs. Data is collected for periods beginning on the 4th of each month.

Heat Energy In The Gas

The energy input is natural gas from ATCO Gas Ltd. It is principally methane atapproximately 95.3% and ethane at 1.8%. ATCO Gas supplies the gas at apressure of 300 to 450 kPa and consumption is metered. The pressure is then reduced to 140 kPa and a sample is continuously monitored for its heating value. This allows for continuous calculation of heat energy input to the fuel cell. The pressure is further reduced to 3.6 kPa prior to use in the fuel cell.

Electrical Energy

Internal Electrical Requirements

The fuel cell stack produces 225 kWe (kilowatts electrical) but approximately 25 kWe of auxiliary power is required to operate the unit. This power is used to operate fan and pump motors, valve operators, etc. The fuel cell is independent of grid-supplied electricity.

Electrical Energy To Grid

The fuel cell reaction produces unregulated direct current electrical energy at approximately 180 VDC. The direct current is regulated and converted to alternating current at 480 VAC within the unit. The voltage is increased to 600 VAC in an external transformer, metered and fed into the NAIT electrical grid. The power meter measures, indicates and records the voltage, amperage, power factor, and phase angles of the power produced. It also indicates a real time calculation of the electrical energy output (megawatt hours) since start-up.

Thermal Energy

In addition to electrical power, the fuel cell reaction produces thermal energy, which must be continuously removed from the unit. Heat is removed from the unit via a high temperature (HT) heat exchanger, low temperature (LT) heat exchanger, and Cooling Module (CM). Some heat also escapes the fuel cell via the process air vent to the atmosphere.

Heat energy flow to the high and low temperature loads and CM is continuously monitored. Thermal meters record and display the temperatures, temperature differences, and flow rates to the loads. They also calculate and totalize energy use and display it as megawatt hours (MWhr) of heating load.

Thermal Energy To HT Heating

Heat energy collected from the HT heat exchanger is used to pre-heat boiler feedwater. A portion of the boiler feedwater is diverted from its normal flow to the boilers, passed through the HT heat exchanger, and returned heated to the boiler water circuit. Boiler feedwater enters the HT heat exchanger at approximately 66°C and leaves at 82°C. This heat addition to boiler feedwater increases the heating plant efficiency.

Thermal Energy To LT Heating Loop

The LT heating load consists of swimming pool heating, domestic hot water heating for showers in the pool area, and make up water heating in the heating plant. The LT heat exchanger transfers heat to the LT heating loop glycol/water mixture. This coolant is circulated to three remote heat exchangers that serve the pool, domestic hot water, and make up water. LT heating coolant leaves the fuel cell at approximately 65°C and returns at 52°C.

Thermal Energy To CM

The CM is a roof top heat exchanger that permits dissipation of heat to the atmosphere in the event of failure or reduction of the heating loads. If the heating loads are not sufficient to remove the heat produced by the fuel cell, flow-regulating valves divert appropriate amounts of the ancillary cooling system water to the CM in order to maintain temperature. Heat expelled by the CM is lost energy and so represents a reduction of thermal efficiency.

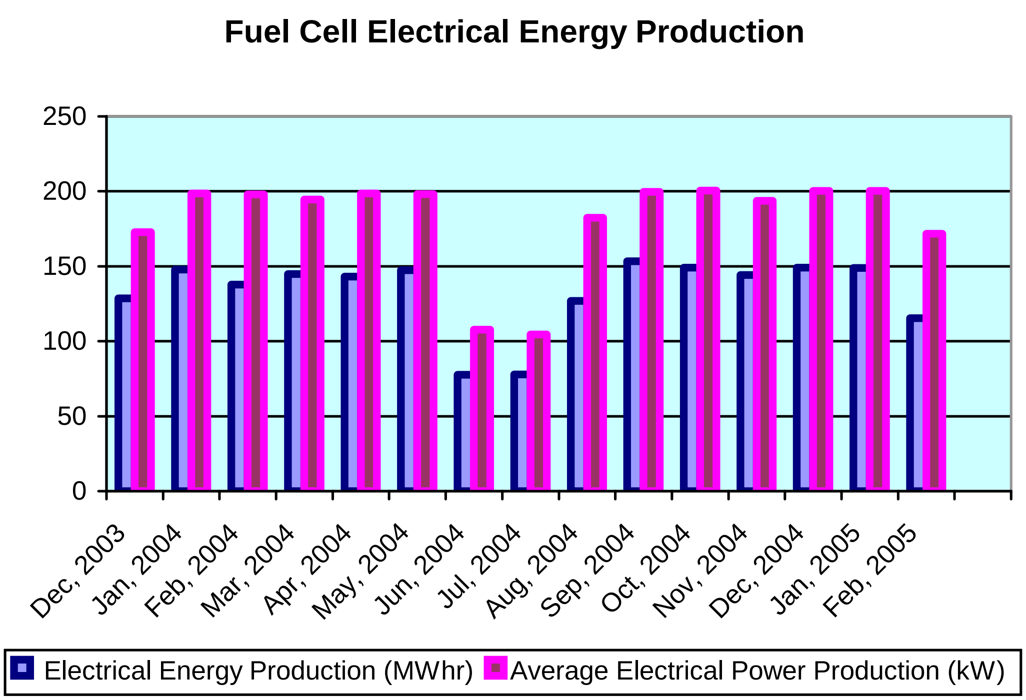
Results and Discussion

FUEL CELL OPERATION

The fuel cell first went on line on November 12, 2003 at 13:05 hrs. Since January 4, 2004 the fuel cell has run a total of 9960 hours at 200 kW. This is a full-load availability of 90.8%. Availability of the fuel cell has been at nearly 100% except for a period during June and July when production was reduced due to UPS and microprocessor failure that necessitated the machine being shut down 12 days in June and 14 days in July.

Electrical Operation

From December 3, 2003, the fuel cell has been at full load (200 kW) 90.75% of the time and except for its shutdown for warranty service has operated at full load for the last five months. As of March 4, 2005, total electrical energy output from the fuel cell has been 2092 MWhr. The average electrical power output of the unit since start-up is 181.5 kW. The fuel cell has been at or nearly at full production during 10 of 15 months of operation.



Thermal Operation

The fuel cell has been providing LT heat since November 17, 2003 and HT heat since November 25, 2003.

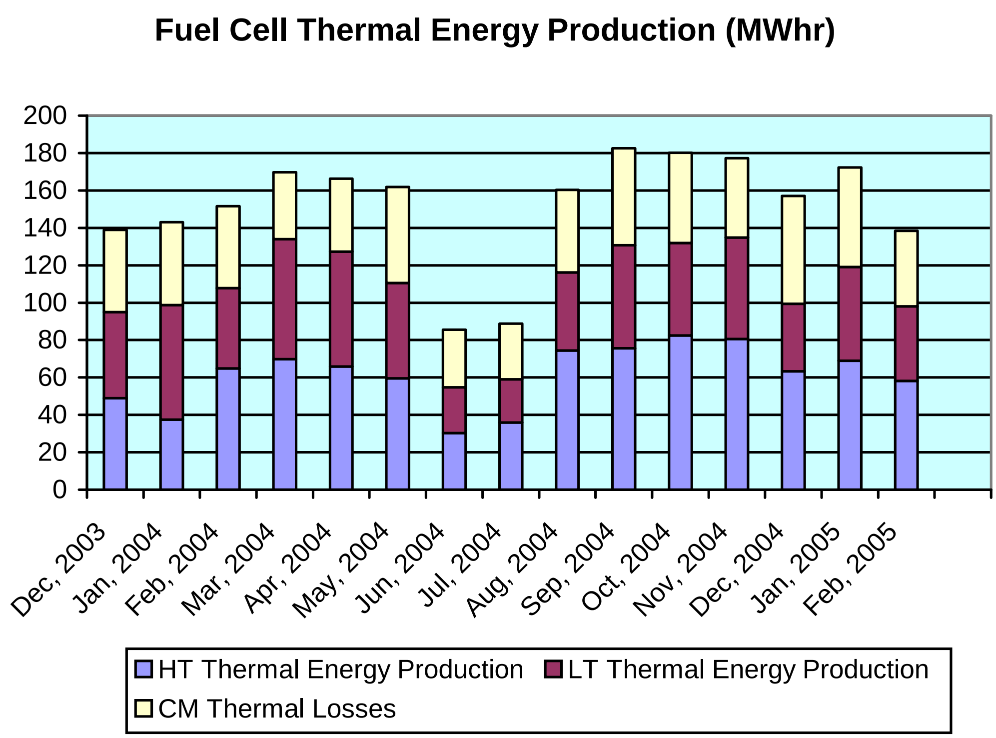
From December 2003 to March 2005, 932 MWhr of HT heat have been produced. Over this period, the average HT heating load was 82.5 kW.

As of March 4, 2005, 679 MWhr of LT heat have been produced. The average LT heating load has been 64.1 kW since the fuel cell was started.

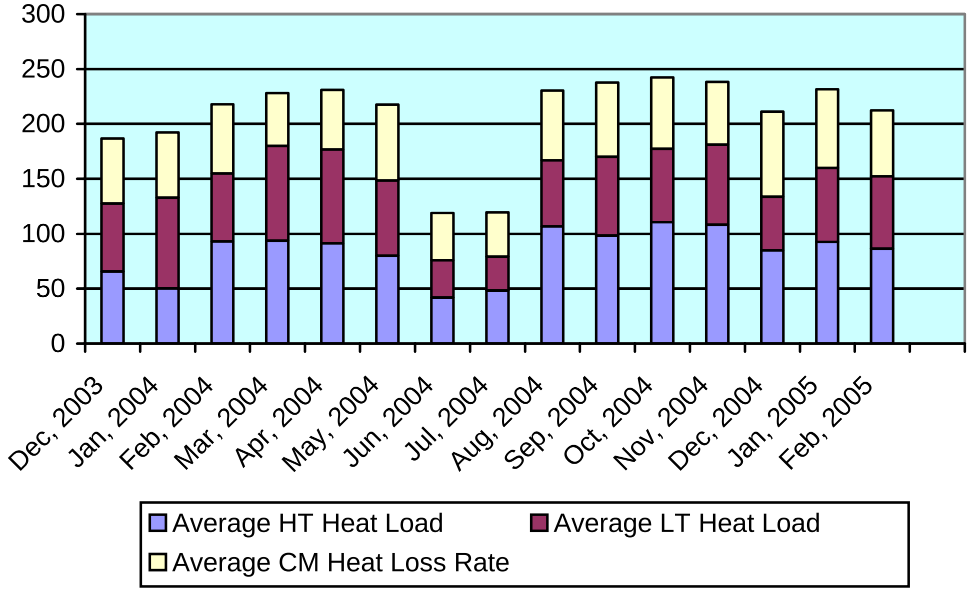
Since start-up, thermal losses to the CM have totaled 712 MWhr. This is approximately 16% of the total energy output of the fuel cell. These losses vary with NAIT operational circumstances including student occupancy as well as boiler load, etc.

Not all heat produced by the fuel cell is captured by the ancillary cooling loop and distributed to the HT, LT, or CM. Some passes out to atmosphere via the process vent. The process vent carries the excess air from the fuel cell stack to the atmosphere. The air contains some water vapor and heat, both of which represent heat lost from the fuel cell.

Carbon Dioxide produced from the reformation of natural gas is also vented carrying some heat out with it. Carbon dioxide is produced at approximately 180 kg/MWhr or about 105.5 kg/hr when the machine is at 200 kW.



Fuel Cell Average Thermal Power Production (kW)



Rated vs. Observed Performance

Electrical power produced by the fuel cell is very close to its rated performance (198.62 kW output to NAIT vs. 200 kW). This difference reflects losses primarily in the 480/600 V transformer.

Rated useful thermal output is approximately 264 kW (900,000 Btu/hr) heat recovery at 200 kW electrical output. This heat recovery is divided about equally between the HT and LT loops and varies with unit load. Heat recovery depends on thermodynamic conditions within the unit such as temperature differences between ancillary cooling water and HT and LT loop circulating water. As well, if the unit load is below 200 kWe, the amount of HT thermal energy available will be proportionally less until at half load essentially no HT heat is available.

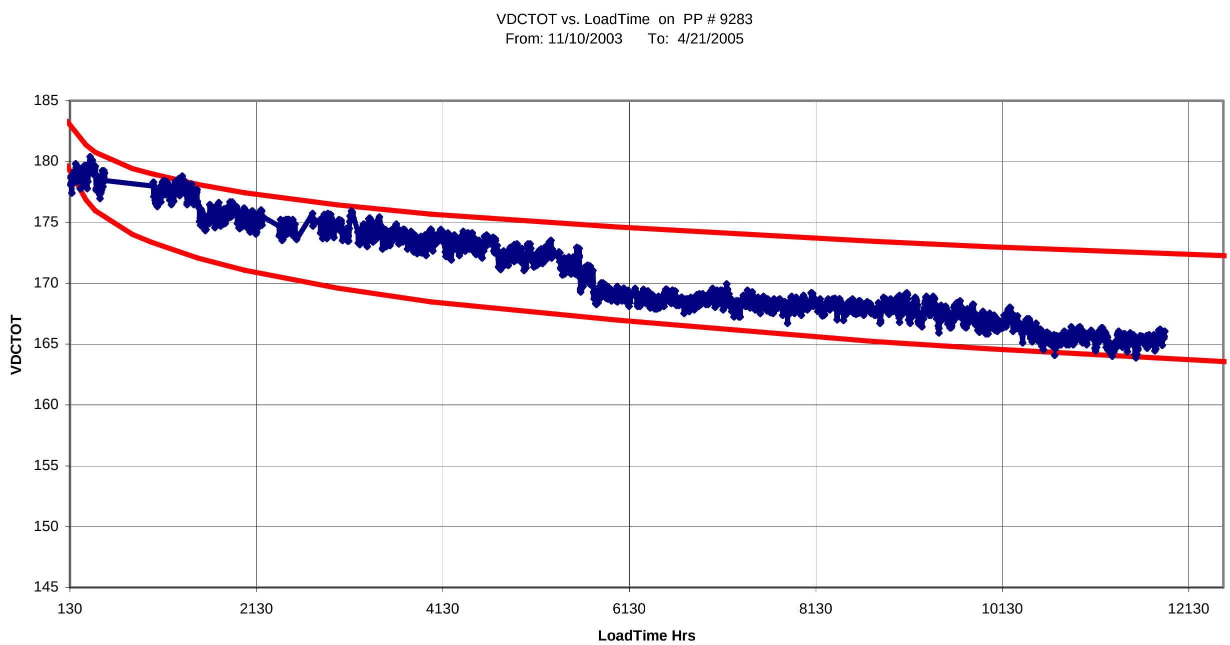
While the fuel cell operating is at 200 kWe, the average heat output rate to the HT and LT loops and CM was approximately 240 kW. This means that thermal recovery was approximately 24 kW below the unit specifications. This, lower than rated heat production, is attributed to lower than expected heat transfer due to lack of heat load and/or less than optimum heat exchange conditions. Primarily this heat loss went to atmosphere via the process vent.

Aging

Since start-up the cell stack output voltage has degraded from about 178 VDC to about 166.6 VDC. This degradation occurs partly as a result of the shutdowns the unit has experienced and partly due to normal operation and is the result of migration of electrolyte into the porous cell plates. Such migration increases the cell resistance resulting in a lower voltage output. According to UTC, the reduction experienced to date is well within expectations of the unit.

Electrolyte migration and consequent voltage reduction is accentuated during shut down periods where the stack is allowed to cool down. During the summer of 2004 the fuel cell was out of operation for about 30 days. The effect on the voltage of the unit is clearly indicated in the graph below at about 5500 hours.

Cell Stack Voltage Degradation



Efficiency

Since start up (until March 04, 2005) the following energy statistics have been obtained:

• Natural gas input (GJ) (per ATCO Gas):	21673.00
• Electrical output (GJ):	7531.20
• HT heat output (GJ):	3355.78
• LT heat output (GJ):	2443.30
• CM output (GJ):	2563.49

The average gross fuel cell efficiency (total outputs/total inputs), since start up, is 73.33%. If the CM losses are removed from the equation, the *net efficiency* of the unit is 61.51%. This net efficiency is very dependent on thermal energy usage.

[1] Data provided by International Fuel Cells a United Technologies Company

During summer months there is a drop in LT heat usage at the pool and showers as well as HT heat transfer to boiler feedwater.

This efficiency may be compared to other newer and traditional technologies. For example, a natural gas fired combined cycle plant has an overall efficiency of about 50%. A coal fired sub-critical generating plant is about 37% efficient and a diesel plant of less than 30%.

Fuel Cell Maintenance

Operation of the unit consists of daily routine supervision and monthly, quarterly, and annual maintenance tasks

Daily Tasks

The Power Plant Operations personnel maintain a detailed and comprehensive log of the fuel cell operation. On a daily basis, they gather data from all energy meters and input the information into an Excel database. They also visually check and verify performance of the fuel cell and operation of the heat recovery systems. As well, they ensure the fuel cell room temperature is maintained between 15°C and 35°C and that the room is secure. The power plant operators indicate that approximately 2 hours per shift are spent on routine supervision of the fuel cell and heating loops.

Monthly Tasks

Monthly checks include a visual inspection of the fuel cell's roof top CM and thermal recovery heat exchangers. Thermal and power meter monthly readings are forwarded to ATCO Gas at the beginning of each month. A water quality analysis is regularly performed on the LT closed loop system to the activities centre.

Quarterly Tasks

The water treatment filter requires quarterly checking and/or cleaning. The process air and cabinet ventilation system air filters require cleaning/replacement or more often as needed. In fact, this has been the case. The air filters have required cleaning/changing several times since start up of the unit. Cooling water pumps require lubrication. The carbon filter and resin beds require replacement whenever the impurity rises above 2 ppm (parts per million). Exhausted resin is transferred out of the bottles and new transferred in. The transfer of resin takes several hours. The bottle exchange is relatively quick using quick-connect fittings.

Annual Tasks

A fuel cell shut down is required every 8000 hours or annually. Tasks related to the water treatment system include demineraliser resin exchange, water tank and degasifier column cleaning, and water filter cartridge replacement. The process air system requires blower lubrication, replacement of the nitrogen passivation filter, flame sensor and spark plug check, and leak checks on valves and hoses in the system. The ancillary coolant system requires filter cleaning and glycol solution testing and evaluation. The cell stack cooling system requires inlet filter cooling, valve and instrumentation inspection, and coolant pump replacement. The electrical system requires checking of circuit breakers, transfer switch, motor starters, power inverters, and power supply as well as the integrity of wiring.

Emergency Shutdowns

The PAFC is designed to run continuously. It is particularly sensitive to shutdowns. Shutdowns provide an opportunity for the semi-liquid phosphoric acid electrolyte to migrate into the porous carbon anode and cathode plates. Each shutdown degrades the voltage output of the machine slightly. To date the fuel cell has experienced 14 shutdowns. Eleven have been emergency shutdowns (ESD), two have been maintenance related and one for its annual shutdown. None of the ESD's has been related to the operation of the cell stack itself. They were principally electrical or electronic in nature and associated with the balance of plant.

Some of the problems that have led to ESD's have been related to improperly programmed thermocouples and valves and a faulty breaker. Other shutdowns resulted from incorrect fan motor rotation on the rooftop CM causing high temperatures in the unit. The sprinkler flow switch and exhaust fan "sail switch" are believed to have caused a number of shut downs. These events occurred during or shortly after the commissioning phase.

The fuel cell control module failed to communicate with Connecticut due to a faulty phone modem on November 28. Replacement of the modem necessitated two planned shutdowns.

The most significant shutdowns occurred in late June and early July and were related to microprocessor and UPS faults. Delays incurred as a result of trying to determine the exact causes and incorrect parts being sent resulted the most significant outage of the unit to date and significantly reduced the unit's performance statistics.

In five of the six months since the outages of June and July, the fuel cell has performed very well; achieving 100% availability at full load until it was shut down for its annual maintenance.

Facility staff, using telephone support provided by the vendor, performed the required maintenance work.

The lost time hours and causes are listed in Appendix I.

Annual Shutdown

The annual shutdown was delayed until February 14, 2005 because of the excellent operation of the unit. Significant repairs included:

- Rebuild the reformer steam control valve
  - No problems were associated with this equipment however the work is scheduled as part of the initial annual maintenance
- Clean the Exhaust Condenser
  - The condenser was very contaminated with phosphoric acid carried over from the cell stack. The condenser was readily cleaned with high-pressure water. UTC expected this carryover. (See photo, Appendix III)
- Rebuild brakes on 4 motor control valves
  - Preventative maintenance task
- Drain, clean, and refill Tank #450 (Ancillary cooling water storage tank)
  - Preventative maintenance task
- Replace all air filters
  - Preventative maintenance task
- Replace resin and carbon filters in the demineraliser
  - Preventative maintenance task
- Flush the LT cooling loop.
  - The loop flow sensing element has been giving incorrect readings and the system was flushed in an attempt to solve the problem

The total time required to complete the annual maintenance was 46 hours. As with ESD's, the facility staff, using telephone support provided by the vendor, performed the annual maintenance work. The fuel cell was back in service at 1200 hrs on February 18, 2005.

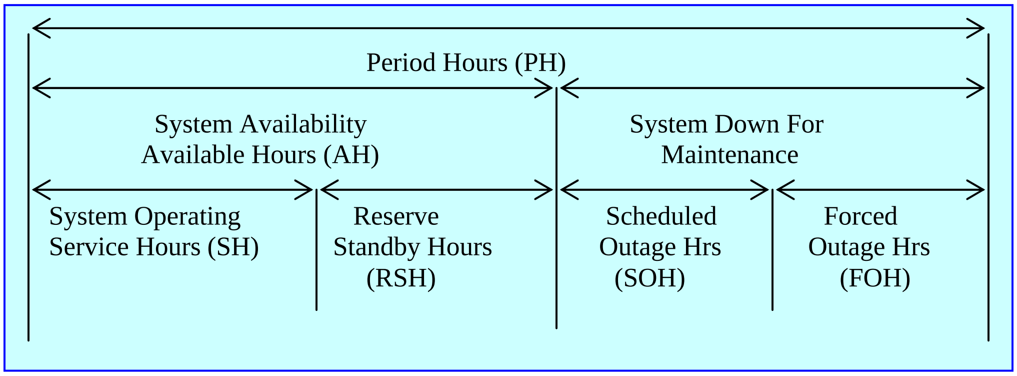
Reliability Statistics

To determine the reliability statistics, definitions are based on those published by the Gas Technology Institute (GTI) in Des Plains, Illinois. GTI is an independent, not-for-profit technology organization that provides products, program, information and services related to energy and the environment, with a focus on the production, delivery, use, and environmental aspects of natural gas.

Definitions:

"There are various ways to measure reliability. In power generation systems, key measures of performance are availability and various maintenance-related indices. The following graphic illustrates different reliability categories for a given period of time (e.g., one year). A power generation system is characterized - depending on its operating state to be in one of these conditions."

The chart below provides a visual explanation of the terms used.



"A number of performance indices can be calculated based on operational and maintenance data".

Reliability Indices	**Hours or %**
Period Hours, PH	8784 hrs
Scheduled Outage Hours, SOH	47 hrs
Forced Outage Hours, FOH	707 hrs
System Available Hours, AH	8030 hrs
System Operating Service Hours, SH	8030 hrs
Period of Demand, POD	8737 hrs
Availability Factor, AF	91.95%
Forced Outage Rate, FOR	8.1%
Schedule outage Factor, SOF	0.5%
Service Factor, SF	91.4%
Mean Time Between Forced Outages, MTBFO	730 hrs
Mean Down Time, MDT	53.8 hrs

Period of Demand (POD):

(Measures the time the unit was planned to operate)

POD = PH – RSH – SOH

The Period of Demand for the unit was 8737 hours during 2004.

Availability Factor (AF,%):

(Measures, on a percentage basis, the unit's "could run" capability. Impacted by planned and unplanned maintenance.)

AF = (PH –FOH)/PH

During 2004 the unit was available for a total of **8077 hours**. This equates to an availability of 91.95% for year 2004.

Forced Outage Rate (FOR,%):

(Measures portion of downtime due to unplanned factors)

FOR = FOH x 100/(SH+FOH)

For 2004, the Forced Outage Rate was **8.1%**. This was due primarily to master microprocessor problems.

Scheduled Outage Factor (SOF,%)

(Measures the percentage of time set aside for planned maintenance.)

SOF = SOH x 100/PH

For 2004, the Scheduled Outage Factor was **0.5%**; due primarily to planned annual maintenance.

Service Factor (SF,%):

(Percent of total period hours the unit is on-line; varies due to site related or economic factors.)

SF = SH x 100/PH

The fuel cell's Service Factor for 2004 was **91.4%**.

Mean Time Between Forced Outages (MTBFO):

(Measures the nominal time between unscheduled forced outages)

MTBFO = PH/# Forced Outages

The Mean Time Between Forced Outages was **730 hours** (approximately 30 days).

From Jan 1/04 to Dec 31/04, the unit tripped seven times. Three trips were due to mechanical factors outside of the fuel cell or operator error. A sail switch in the exhaust ducting is believed to have caused two of these trips. The sail switch was installed to monitor flow through the ducting installed to conduct exhaust gases out of the building. The manufacturer did not require this precaution. The sail switch trip function was removed and this problem ceased.

Four trips directly attributable to the fuel cell were all due to communications failures in the master microprocessor, which was eventually replaced and problems ceased. During this time, between June 1 and August 1, the fuel cell was not at full load for 392.3 hours.

Mean Down Time (MDT):

(Measures the nominal duration the unit is down during maintenance events)

$$\mathbf{MDT = \frac{SOH + FOH}{\#\ ESD + PSD} \times 100}$$

The mean down time for 2004 has been 53.9 hours. This high value is due mainly to problems related to the master microprocessor and UPS. The master microprocessor was replaced twice as well as three slave cards.

Cost Parameters

Operating costs have been essentially variable costs. There has been no requirement to hire staff to operate the fuel cell. Existing heating plant operators have provided the monitoring and maintenance requirements as part of their building management function.

Total Fuel Cell Plant Capacity

- The net electrical output of the fuel cell is rated at 200 kWe
- The maximum thermal energy recovery of the fuel cell at 200 kWe output is rated at 264 kWt

Total Fuel Cell Plant Cost

- Fuel Cell Cost C $1,273,000 (US $980,000)
- Installation Cost: C $1,000,000 (US $770,000)
- Total Cost: C $2,730,000 (US $1,750,000)

Variable Operating Costs

The operating costs consist of no-fuel related costs and fuel gas costs.

Non-Fuel Operating Expenses Totals For 2004		
Month	CAN$	US$
JAN	$2,862.51	$2,200.21
FEB	$1,949.90	$1,498.75
MAR	$476.23	$366.04
APR	$1,936.78	$1,488.67
MAY	$140.06	$107.65
JUN	$2,342.24	$1,800.31
JUL	$1,918.08	$1,474.29
AUG	$590.00	$453.49
SEP	$1,701.30	$1,307.67
OCT	$247.17	$189.98
NOV	$1,370.82	$1,053.66
DEC	$1,723.00	$1,324.35

Consumables

In the agreement, consumables are an expense to ATCO Gas. Generally consumables consist of items and material that are required to carry on normal operation of the fuel cell. Examples of consumables are natural gas, nitrogen and helium gases, filters, and demineraliser resin. Some consumables use occurs as a result of existing conditions. For example, the air quality will govern the frequency of air filter replacement. The resin beds require replacement whenever circulation water concentration reaches 2 ppm. Nitrogen purge gas reserve replenishment is required depending on the number of start ups and shutdowns the unit goes through. As of March 2005, the value of consumables other than natural gas has totaled C $22,933. This is less than 1 cent per kWh of energy produced and used.

Itemized non-fuel expenses are given in Appendix II.

Fuel Gas Costs

Fuel Gas Consumption Data					
Month	Consumption (GJ)	Days	GJ/Day	GJ/hr	Cost (CND)
JAN	1,482	31	47.8	2.0	$9,602.32
FEB	1,455	32	45.5	1.9	$9,405.70
MAR	1,263	28	45.1	1.9	$7,383.62
APR	1,441	31	46.5	1.9	$8,543.26
MAY	1,620	33	49.1	2.0	$10,316.65
JUN	1,236	33	37.4	1.6	$11,353.01
JUL	543	31	17.5	0.7	$4,289.40
AUG	1,330	32	41.6	1.7	$10,597.66
SEP	1,426	24	59.4	2.5	$11,287.20
OCT	1,660	32	51.9	2.2	$11,028.47
NOV	1,543	30	51.4	2.1	$10,531.92
DEC	1,437	28	51.3	2.1	$10,092.93

In 2005 natural gas prices varied from a low of $5.846 per GJ to a high of $7.966 with an average price of C$7.045/GJ (**$5.41/MBTU US$**) for the year.

For the year 2004, total fuel gas consumption of 16436 GJ cost C $114,432.14, (**$87995.96, US$**). From start up to March 04/05, the natural gas consumed by the fuel cell has been 21673 GJ.

Local Area Electrical Rate

- The average Electrical rate for 2004 was $0.1014/ kWh $C (**8.19 cents/kWh, US$**).

Heat Rate

- The average heat rate for the fuel cell was **2913.3 BTU thermal/ kWh** electrical.

Capacity Factor

- During 2004 the fuel cell operated at full load a total of 7946 hrs. During this time its output was 198.71 kWe. This is a capacity factor of 99.36%.

Energy (Electrical & Thermal) Output

	Main Campus Electrical Consumption (KWhr)	Fuel Cell Electrical Energy Production (KWh)	Fuel Cell Thermal Energy Production (KWh)	% Facility Electrical Energy Produced By Fuel Cell	% Facility Thermal Energy Produced By Fuel Cell
JAN	2,043,427	147,798	144,744	6.74%	10.76%
FEB	2,013,984	137,722	107,840	6.40%	10.87%
MAR	2,139,789	144,744	134,000	6.34%	11.53%
APR	2,025,753	143,004	127,370	6.59%	11.78%
MAY	2,007,004	147,463	110,580	6.84%	11.39%
JUN	2,094,836	77,605	54,700	3.57%	5.94%
JUL	2,139,415	77,818	58,940	3.51%	6.01%
AUG	2,057,038	127,003	116,130	5.82%	10.57%
SEP	2,041,312	153,333	130,720	6.99%	12.22%
OCT	2,083,793	149,148	131,960	6.68%	11.89%
NOV	2,013,138	144,117	134,750	6.68%	12.17%
DEC	1,806,831	149,063	159,400	7.62%	14.58%

During 2004, the fuel cell provided an average of 6.15% of the main campus electrical load and 10.81% of its thermal load.

The fuel cell's thermal output was divided between high temperature heat recovery and low temperature heat recovery:

- 2880.18 GJ (**2729.87 MBTU**) of HT heat recovered
- 2034.18 GJ (**1928.02 MBTU**) of LT heat recovered

Environmental Impact

Reduction of Greenhouse Gases:

Operation of the 200 kW fuel cell has produced electrical and heat energy used by NAIT in place of energy that would have been purchased from electrical suppliers or produced by NAIT's heating plant. For the year 2004, the fuel cell produced approximately:

- 1600 MWhr of electrical energy that was used in the NAIT grid
- 365 MWhr of heat energy that was used to heat the NAIT swimming pool and pool showers as well as to increase the efficiency of the facility's heating plant.

The fuel cell operates at a net efficiency of approximately 66% - much higher than that of conventional sources of energy. As a result of using less energy, the fuel cell reduces NAIT's production of greenhouse gases.

Had it been supplied from the Alberta electrical grid, 1600 MWhr of imported electrical energy would have required the release **1600 tonnes** of carbon dioxide (CO_2) when generated in a thermal generating station.[2]

Heat produced by the fuel cell operation was captured and used instead of heat being supplied by the NAIT Heating Plant. Assuming 80% efficiency for the plant, the 1365 MWhr of fuel cell produced heat is equivalent to 1606 MWhr (or 5780 GJ) of natural gas energy.[3] Burning this amount of gas in NAIT's boilers would have produced approximately **300 tonnes** of CO_2.[4]

During 2004 the fuel cell used approximately 16147 GJ of natural gas fuel. This gas (92% methane) is converted to hydrogen in a reformer: a process that produces CO_2. Using 16147 GJ of natural gas in the fuel cell produced approximately **800 tonnes** of CO_2.

Therefore, in 2004, by using its fuel cell to supply part of its energy load, NAIT reduced the amount of CO_2 produced by **1100 tonnes**. Since start-up, the fuel cell has reduced NAIT's CO_2 load by approximately 1650 tonnes.

As well, fuel cells do not produce SO_x or NO_x. Any sulphur contained in the fuel gas is trapped and retained in the desulphuriser vessel before it passes into the reformer. Nitrous Oxides are not formed because the fuel cell reaction does not produce enough heat to promote NOx production. Therefore, the 1965 MWhr of energy used by NAIT came without any contribution to environmental levels of SO_x or NO_x.

[2] ATCO Gas: (1 MWhr of electrical power imported by NAIT from the Alberta Power Grid releases 1 tonne of CO_2)
[3] 1 MWhr of energy = 3.6 GJ of energy
[4] ATCO Gas: (1000 GJ of natural gas produces 50 tonnes of CO_2)

Intangible Environmental Benefits:

The project has a strong education focus. Fuel cell training programs for day and night students will be presented at NAIT in the fall of 2005 as part of the Power Engineering Program. The interpretive centre has been established and a program to attract junior high and high school students as well as the general public is being developed.

The interpretive centre will increase the public awareness of fuel cells and generate discussion of environmental issues. It will also generate interest in students in fuel cell and environmental technology.

Conclusions

The PC25C fuel cell plant at NAIT has successfully completed its first full calendar year of operation. In fact it continues to operate successfully.

The acquisition, start up, and operation of the fuel cell has been a success. It was commissioned and started with few problems and it continues to perform well. Except for problems with the microprocessor and UPS in June and July of 2004, the unit has performed very well. Not considering this period, the fuel cell has a 97.5% availability.

This success is seen in that the fuel cell produces electrical and thermal energy to the facility with greater efficiency than conventional means and so is producing energy to a lower greenhouse gas contribution by an estimated 1100 tonnes of carbon dioxide. It has operated within the parameters given by the vendor and has not imposed excessive operating and maintenance costs. The maintenance required to date has been well within the expertise of the facility staff with phone assistance from the vendor.

The project is providing learning opportunities for NAIT students. NAIT students are already using the fuel cell as a learning tool and enthusiastically participated in developing the interpretive centre. The implementation in 2006 of day program and evening program fuel cell related courses will provide an opportunity for NAIT students and the public to study fuel cells and related issues. Acquisition of the 5 kW fuel cell and smaller fuel cell equipment for use in NAIT's Power Engineering lab will provide its students with an opportunity to get real hands-on experience operating and monitoring fuel cells.

As well the project is providing an opportunity for junior and senior high school students as well as the general public to learn about fuel cells and environmental issues by touring the interpretive centre and visiting the fuel cell web site. To date there has been considerable expression of interest by junior and senior high schools in touring the interpretive centre. Since the interpretive centre has opened, NAIT has conducted tours of over 800 participants comprising professional and technical organizations, schools, and the general public.

Development of an interpretive centre around the fuel cell demonstrates NAIT's effort and commitment to increasing public and student knowledge of fuel cells and environmental issues. Fuel cell related courses demonstrate NAIT's commitment to training in environmental technology.

The project is also enabling NAIT to cooperate with other learning institutions and research facilities in increasing knowledge about fuel cell applications.

Tables and Appendices

I. Lost Time Hours

Date	Time Off	Time On	Hours Off (Approx)	Type	Cause
11/12/2003	0710	1305	6	ESD	Cooling Fans running Backward
11/19/2003	0530	0740	2.2	ESD	U/C relay
11/25/2003	1630	?	(est.) 3.00	ESD	HT loop TCV setting to high
12/05/2003	1105	1120	0.25	PSD	S/D to change modem
12/05/2003	1235	1538	3.0	ESD	Inverter high temp (room too hot)
12/19/2003			(est.) 0.50	PSD	Replace Modem
01/10/2004	1325	1425	1.0	ESD	PE400 high or Operator Error
03/29/2004	2331		7.5	ESD	Exhaust Sail Switch
03/30/2004		1246			
04/02/2004	1030	1112	0.75	ESD	Exhaust Sail Switch
06/18/2004	1631		288.0	ESD	MDSP (Master Microprocessor) & UPS Fault
06/30/2004		1335			
06/30/2004	1345		1.00	ESD	MDSP (Master Microprocessor)
07/02/2004		1330			
07/12/2004	1227		25.50	ESD	MDSP (Master Microprocessor)
07/13/2004		1422			
07/13/2004	1906		369.25	ESD	MDSP (Master Microprocessor)
07/27/2004		1415			
02/14/2005	1400		46	PSD	Annual Shutdown
02/18/2005		1200			
Total SD hrs 753.95; ESD hrs 707.2					

Table title: Lost Time Hour

II: Non-Fuel Operating Expenses

Itemised Non-Fuel Operating Expenses For 2004			
Date	Vendor	Expense Item	Cost (CDN)
01/05/2004	UTC	Filter	$1,233.00
01/05/2004	UTC	Filter	$144.00
01/05/2004	UTC	Brake	$1,068.00
01/05/2004	UTC	Amplifier	$148.00
01/05/2004	UTC	Filter	$156.00
01/21/2004	BOC Gases	Helium	$12.73
01/21/2004	BOC Gases	Helium	$100.78
02/10/2004	SAI	Resin	$1,819.00
02/26/2004	BOC Gases	Bottle Rental	$130.90
03/17/2004	BOC Gases	Nitrogen	$336.17
03/30/2004	BOC Gases	Bottle Rental	$140.06
04/01/2004	SAI	Resin	$1,476.60
04/02/2004	BOC Gases	Nitrogen	$320.12
04/29/2004	BOC Gases	Bottle Rental	$140.06
05/28/2004	BOC Gases	Bottle Rental	$140.06
06/23/2004	BOC Gases	Nitrogen	$336.17
06/28/2004	UTC	Filter	$1,515.07
06/29/2004	BOC Gases	Nitrogen	$320.12
06/29/2004	BOC Gases	Bottle Rental	$170.88
07/05/2004	BOC Gases	Nitrogen	$336.17
07/15/2004	BOC Gases	Nitrogen	$652.55
07/29/2004	BOC Gases	Nitrogen	$636.50
07/29/2004	BOC Gases	Bottle Rental	$292.86
08/11/2004	BOC Gases	Nitrogen	$590.00
09/24/2004	SAI	Resin	$1,701.30
10/19/2004	SAI	Activated Carbon	$247.17
11/16/2004	BGE	Filters (8)	$355.20
11/17/2004	BOC Gases	4 Bottles Nitrogen	$320.12
11/17/2004	BOC Gases	Combustion Gas	$695.50
12/08/2004	UTC	C90 Retrofit Kit - 4	$1,132.00
12/08/2004	UTC	Filter 401 - 4	$32.00
12/08/2004	UTC	CV-500 Gaskets - 4	$64.00
12/08/2004	UTC	Steam Valve CV-500	$495.00

III: Photographs

Photograph #1

Fuel Cell Installation

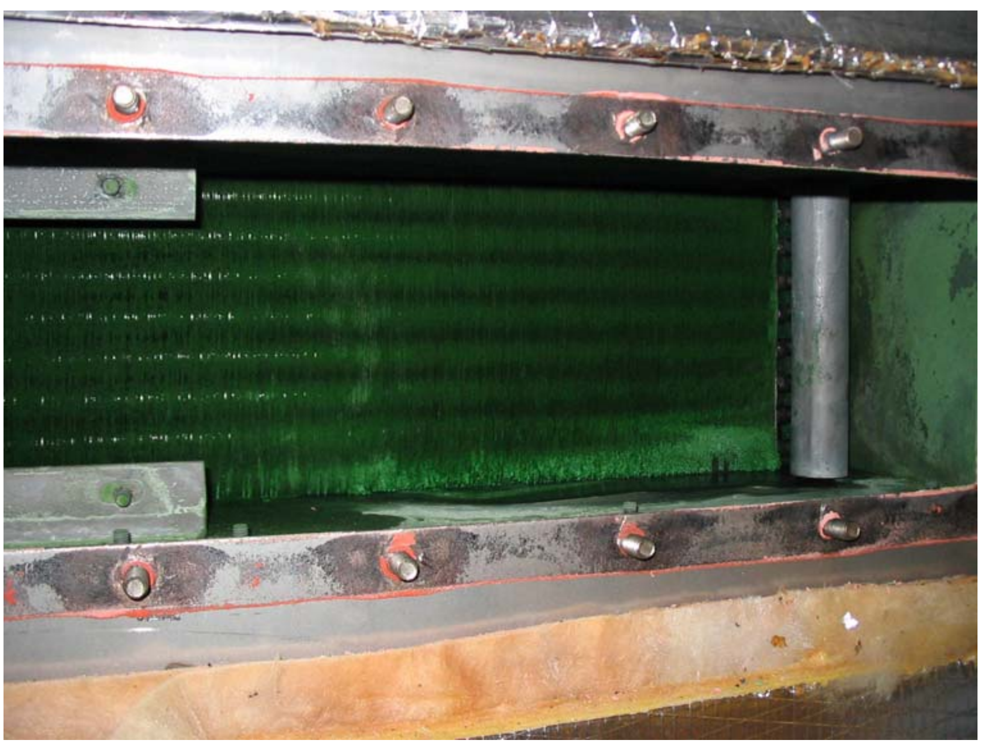
Photograph #2

Interpretive Centre

Photograph #3

Thermal Recovery Piping

Photograph #4



Phosphoric Acid Contaminated Exhaust Condenser

References

None.

Bibliography

None.